WO02060810

Publication Title:

MICRO-ELEMENT SUBSTRATE INTERCONNECTION

Abstract:

Abstract of WO02060810

Micro-element package comprising a lower substrate in which can be embedded a micro-element chip, for example a fluidic micro-sensor or a micro-electronic component, an upper substrate and a gasket intermediate the substrates characterised in that one of said substrates includes two or more protruding pillars and the other of said substrates includes a number of recesses corresponding to the number of pillars and into which said pillars can locate so as to releasably hold said substrates together.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 August 2002 (08.08.2002)

PCT

(10) International Publication Number
WO 02/060810 A2

(51) International Patent Classification[7]: B81B 7/00

(21) International Application Number: PCT/GB02/00399

(22) International Filing Date: 30 January 2002 (30.01.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0102326.6 30 January 2001 (30.01.2001) GB

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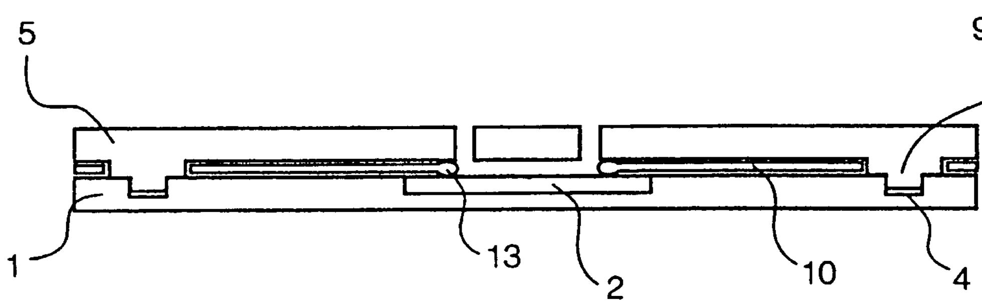
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MICRO-ELEMENT SUBSTRATE INTERCONNECTION



(57) **Abstract:** Micro-element package comprising a lower substrate in which can be embedded a micro-element chip, for example a fluidic micro-sensor or a micro-electronic component, an upper substrate and a gasket intermediate the substrates characterised in that one of said substrates includes two or more protruding pillars and the other of said substrates includes a number of recesses corresponding to the number of pillars and into which said pillars can locate so as to releasably hold said substrates together.

WO 02/060810 A2

MICRO-ELEMENT SUBSTRATE INTERCONNECTION

This invention relates to a method for the mechanical, electrical and fluidic interconnection of substrates containing embedded micro-elements, in particular but not exclusively fluidic micro-sensors or microelectronic components.

The packaging of fluidic micro-sensors presents some new challenges to the microelectronics industry. The package must be such that fluid can reach the micro-sensor without affecting nearby associated electronics. This implies the presence within the package of fluidic "plumbing" in parallel with electrical (and possibly optical) circuitry.

Many micro-sensor packaging schemes rely on processes such as silicon and anodic bonding, however these techniques cannot be used with many fluidic micro-sensors because they contain sensitive organic membranes that will not survive the necessary elevated processing temperatures.

There has been a considerable amount of research into the production of micro-fluidic channels on various substrates, ranging from silicon to plastics, however little attention has been paid to the interfaces between these substrates and the outside world. Many micro-fluidic packages simply rely on tubes that are either crudely glued or press-fitted into place. More recently a fine pitch fluidic connector has become available from Lawrence Livermore National Laboratory.

It is possible to make electrical connections to fluidic micro-sensors using standard electronics packaging

techniques such as wire bonding and flip chip bonding. However, it can be difficult to employ standard electrical interconnection methods such as these because of the need for elevated processing temperatures. Alternatively, Z-axis conductive elastomer sheet can be used (e.g. Fujipoly), however this requires some clamping arrangement.

Fluidic circuit boards which accommodate more than one micro-sensor have been developed, however they rely on anodic bonding to obtain fluidic seals, which has the disadvantage mentioned above. The ability to replace individual sensors within a system would be highly desirable in systems where the sensors are single-use devices or have a limited lifetime. For example a blood analysis system has been developed by i-STAT which relies on a disposable cartridge containing a blood micro-sensor. However, this system means that the entire cartridge has to be disposed of after use, as it is not possible simply to remove and replace the micro-sensor.

A further problem identified when developing a three-dimensional micro-fluidic system (i.e. one containing more than one substrate) is the need for significant compressive force between the substrates in order to make an effective fluidic seal.

It is therefore an object of the present invention to provide a fluidic micro-element packaging technique which alleviates the above-described problems. In particular, it is an object of the invention to facilitate the replacement of individual sensors within a three-dimensional module containing more than one micro-sensor or microelectronic component. Furthermore, it is an object of the invention to provide a technique to align,

stack and interconnect substrates in which micro-elements such as fluidic micro-sensors or micro-electronic components are embedded.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a micro-element package comprising a lower substrate in which can be embedded a micro-element chip, for example a fluidic micro-sensor or a micro-electronic component, an upper substrate and a gasket intermediate the substrates characterised in that one of said substrates includes two or more protruding pillars and the other of said substrates includes a number of recesses corresponding to the number of pillars and into which said pillars can locate so as to releasably hold said substrates together. This arrangement means that the package can be readily disassembled when required to remove and replace the micro-element if it is, for example a single use sensor or is of limited life. Furthermore, the alignment of the pillars in the recesses with the gasket in between means that the substrates and gasket can be accurately aligned so as to define the desired flow path of the fluid in the active area of the micro-sensor chip.

Preferably, two or more of said pillars each include an endstop which limits the extent to which the pillar can locate in one of said recesses. A limit to the vertical separation of the substrates means that the compressive force on the gasket between the substrates is defined and this can be arranged to optimise the fluidic seal provided by the gasket, without risk of providing too great a compressive force.

Preferably, each pillar and each recess is substantially circular in lateral cross-section. Ideally, there are four of said pillars and four of said recesses.

In a preferred form, said gasket includes an embedded O-ring which, in use, forms a fluidic seal between the O-ring and the upper and lower substrates. The position of the O-ring defines the path through which fluid can flow.

Preferably, said pillars are provided on said lower substrate and said recesses are provided on said upper substrate. It is envisaged however that the reverse may alternatively be employed.

Preferably, an electrically conductive elastomer ring is fitted to at least one of said pillars so as to provide electrical interconnection between said substrates.

Alternatively, at least one of said pillars and the recess in which it is located includes an electrically conductive via which provides electrical interconnection between said substrates. Ideally, the micro-element package further includes an electrically conductive elastomer pad intermediate said at least one pillar and said recess.

In a further preferred form, at least one of said pillars and the recess in which it is located includes a fluidic via or bore which provides fluidic interconnection between said substrates. Ideally, the micro-element

package further comprises a fluidic seal between said at least one pillar and said recess.

Preferably, said gasket provides electrical interconnection between said substrates by means of one or more upstanding columns thereon which are vertically electrically conductive. Ideally, said columns are vertically electrically conductive by means of oriented conductive wires embedded therein. Alternatively, said columns are made from a metal-filled compliant elastomer, for example metal-loaded silicone.

In a preferred form, one of said substrates is provided with said pillars on one surface thereof and is provided with recesses for receiving pillars of another substrate on the opposing surface thereof. In this way, a stack of more than two substrates can be formed and hence a package containing more than one micro-element can be obtained.

According to a second aspect of the invention there is provided a gasket for use in a micro-element package wherein said gasket provides electrical interconnection between substrates within the micro-element package by means of one or more upstanding columns thereon which are vertically electrically conductive.

Preferred embodiments of the present invention will now be more particularly described, by way of example only, with reference to the accompanying drawings in which:

Figure 1A is an exploded cross-sectional view of stacked substrates embodying the first aspect of the invention;

Figure 1B is a cross-sectional view of the assembled substrates of Figure 1A;

Figure 2A is an exploded cross-sectional view of a pillar and recess having a conductive via;

Figure 2B is a cross-sectional view of the assembled pillar and recess of Figure 2A;

Figure 3A is an exploded cross-sectional view of a pillar and recess having an elastomer ring;

Figure 3B is a cross-sectional view of the assembled pillar and recess of Figure 3A;

Figure 4A is an exploded cross-sectional view of a pillar and recess having sealing gasket;

Figure 4B is a cross-sectional view of the assembled pillar and recess of Figure 4A;

Figure 5A is an exploded cross-sectional view of a pillar and recess having an O-ring seal;

Figure 5B is a cross-sectional view of the assembled pillar and recess of Figure 5A;

Figure 6A is an exploded cross-sectional view of a pillar and recess having a combined electrical and fluidic interconnection;

Figure 6B is a cross-sectional view of the assembled pillar and recess of Figure 6A;

Figure 7 is a perspective view of a gasket; and

Figure 8 is an exploded view of part of a modular integrated micro-system.

Referring firstly to Figures 1A and 1B, a lower substrate 1 includes a central recess in which is embedded a fluidic sensor chip 2. At each end of the lower substrate 1 is a recess 3, 4 which is circular in lateral cross-section.

An upper substrate 5 is provided in which there are two centrally located fluid ports 6, 7. When the upper and lower substrates are assembled (as shown in Figure 1B), the fluid ports 6, 7 are aligned with the active area 8 of the embedded sensor chip 2.

At each end of the upper substrate 5 are pillars 8, 9, which are circular in lateral cross-section and which are suitably shaped to fit into the recesses 3, 4 in the lower substrate 1 (as shown in Figure 1B).

Each of the pillars 8, 9 is provided with a pillar lip 8′, 9′ so that the pillars 8, 9 have a stepped or tiered appearance in the illustrated cross-sectional view. The pillar lips 8′, 9′ limit how deeply the pillars 8, 9 can locate into recesses 3, 4 and therefore act as endstops.

A sheet of elastomeric material 10 sits between the upper and lower substrates 5, 1. Apertures 11, 12 in the elastomeric sheet 10 enable it to be aligned with respect to the pillars 8,9. As shown in Figure 1B, when the substrates are assembled, the pillars 8,9 pass through apertures 11, 12 respectively so that they (the pillars) can locate in recesses 3, 4 respectively.

The elastomeric sheet 10 contains an embedded O-ring 13 which is positioned so as to surround the active area 8 of the embedded sensor chip 2, when the substrates are assembled. The pillar lips 8′, 9′ define the extent to which the embedded O-ring 13 is compressed when the substrates are sandwiched together by application of an external force. This ensures that sufficient compressive force is applied to make an effective fluidic seal between the O-ring 13 and the substrates 1,5 but without risk of excessive force being applied.

As illustrated in Figure 1B, the resulting stack of substrates 1, 5 enables fluid to be fed to the active area 8 through the fluid ports 6, 7 in the upper substrate 5. Accurate alignment of the fluid ports 6, 7 with the active area 8 is achieved by the location of the pillars 8, 9 in the recesses 3, 4. If the pillars are a simple snap-fit into the recesses then the substrates can be easily disassembled when required if it is necessary

to replace the sensor 2. This modular arrangement has particular application where single-use sensors are used (for example in blood analysis), where the sensor has a limited or short life, or where it is desirable to reconfigure the system to perform different tasks by inserting different sensors.

It is envisaged that more than two substrates could readily be stacked by providing recesses on the uppermost surfaces and pillars on the lowermost surfaces of each substrate. In this way a multi-sensor module containing more than one fluidic micro-sensor can be produced. The stack can easily be disassembled if it is necessary to replace an individual sensor. In an alternative embodiment, the pillars could be provided on the uppermost surfaces and the recesses on the lowermost surfaces of each substrate.

A further key advantage of the invention is that the pillars 8, 9 can be utilised to provide electrical and fluidic connections as depicted in Figures 2A to 6B.

Referring to Figures 2A and 2B, electrical connection between the upper and lower substrates 5, 1 can be achieved by the incorporation of a conductive via 14 through the centre of the pillar 9 and recess 4. The conductive via 14 is in electrical contact with the surface tracks 15 which are on the exterior surfaces of the upper and lower substrates. A conductive elastomer pad 16 situated in the base of the recess 4 provides a compliant or pliable contact between the two surface tracks.

Alternatively, if the surface tracks 15 are on the interior surfaces of the substrates, electrical connection can be achieved as illustrated in Figures 3A and 3B by adding a ring of conductive elastomer 17 to the pillar lip 9'.

Referring now to Figures 4A to 5B, fluidic connection between two substrates is achieved by providing a bore 18 through the centre of the pillar 9.

A fluidic seal is achieved as illustrated in Figures 4A and 4B by providing a gasket 19 either in the base of the recess 4 or on the pillar lip 9'. Alternatively, as illustrated in Figures 5A and 5B, a fluidic seal is created by providing an O-ring 20 between the end of the pillar 9 and the recess 4.

Combined electrical and fluidic interconnection of the substrates can be achieved by combining the methods described above for example as illustrated in Figures 6A and 6B.

A further preferred feature of the invention comprises a custom gasket which combines the task of a normal gasket (i.e. to provide a fluid seal) together with providing vertical electrical interconnection for two substrates. The custom gasket 21, illustrated in Figure 7, consists of a sheet of compliant material (e.g., silicone rubber) of the same general shape as the substrates between which it is to be placed.

The gasket 21 has four apertures 22 in the corner regions thereof which, in use, accommodate the pillars as they locate in the recesses.

The gasket 21 also comprises a plurality of upstanding columns 23 of compliant material that are vertically electrically conductive. In the embodiment illustrated in Figure 7, conductivity is obtained by means of embedded vertically oriented wires 24. Alternatively, vertical conductivity is obtained by making the columns from a metal-filled compliant elastomer, for example metal-loaded silicone.

The path through which a fluid will flow when the gasket is compressed between two substrates is defined by means of an elongate aperture 25 bordered by a raised but compressible lip 26 having an O-ring cross-section. This has the advantage of reducing the compressive force required to effect a fluidic seal (compared to a conventional planar gasket).

Figure 8 shows how the gasket 21 is incorporated into a modular integrated micro-system. The lower substrate 1 including the embedded fluidic microsensor chip 2 is shown with four upstanding pillars 8, 8A, 9, 9A. The lower substrate 1 also has four vertically upstanding electrically conductive columns 27, of similar construction to the columns 23 on the gasket 21.

The gasket 21 is assembled with the lower substrate 1 by fitting the apertures 22 over the pillars 8, 8A, 9, 9A so that the compressible lip 26 defines a fluid path aligned with the active area of the sensor chip 2.

The upper substrate 5, in this case a signal re-routing layer includes a further set of four pillars, each having a recess 3, 3A, 4, 4A at the interior thereof to accommodate one of said pillars 8, 8A, 9, 9A of the lower substrate 1. The pillars 8, 8A, 9, 9A of the lower substrate 1 are snap-fitted into the recesses 3, 3A, 4, 4A of the upper substrate 5 in order to physically assemble the integrated micro-system. Once assembled, vertical electrical interconnection is achieved by the connection of columns 27 on the lower substrate with columns 23 on the gasket and finally surface tracks 28 on the upper substrate.

The substrates 1, 5 may be milled from plastics such as polycarbonate or polymethylmethacrylate (Perspex), or made by injection moulding or hot embossing; the choice of substrate material depending upon the type of fluids with which it is intended to come into contact.

Once the substrates 1,5 and gasket 21 are assembled into a stack, the stack can be fitted into a holder (not shown) which provides electrical and fluidic connections to a motherboard. The holder may accommodate several substrate-gasket pairs and is designed to apply the optimum compressive force for the number of gaskets present. The motherboard contains the necessary electronics for control and analysis of data from the micro-sensors 2, together with fluidic sample introduction ports and a pump.

The present invention provides an effective packaging technique for fluidic or other types of micro-elements.

Although the preferred embodiments have been described in relation to a fluidic micro-sensor, the invention is also applicable to non-fluidic micro-elements such as micro-electronic components.

No specialist manufacturing equipment is required, thus making the packages easy to produce. Prototype substrates have been made using a CNC milling machine and it would be straightforward to scale up production by using hot embossing or injection moulding techniques. Various methods for plating the substrates are available. A pick and place machine together with a fluid dispensing system would enable micro-elements to be embedded in the substrates and the same system could be employed to create electrical vias. Planar conductive gaskets are already commercially available however, custom three-dimensionally structured conductive gaskets such as that described above could be made by casting an elastomer against a patterned photoresist or by using a photo-imageable elastomer.

The technique described herein thus provides a versatile three-dimensional modular integrated micro-system with potential applications, for example, in the environmental and medical fields.

CLAIMS

1. Micro-element package comprising a lower substrate in which can be embedded a micro-element chip, for example a fluidic micro-sensor or a micro-electronic component, an upper substrate and a gasket intermediate the substrates characterised in that one of said substrates includes two or more protruding pillars and the other of said substrates includes a number of recesses corresponding to the number of pillars and into which said pillars can locate so as to releasably hold said substrates together.

2. Micro-element package as claimed in claim 1 wherein two or more of said pillars each include an endstop which limits the extent to which the pillar can locate in one of said recesses.

3. Micro-element package as claimed in claim 1 or claim 2 wherein each pillar and each recess is substantially circular in lateral cross-section.

4. Micro-element package as claimed in any of the preceding claims wherein there are four of said pillars and four of said recesses.

5. Micro-element package as claimed in any of the preceding claims wherein said gasket includes an embedded O-ring which, in use, forms a fluidic seal between the O-ring and the upper and lower substrates.

6. Micro-element package as claimed in any of the preceding claims wherein said pillars are provided on said lower substrate and said recesses are provided on said upper substrate.

7. Micro-element package as claimed in any of claims 1 to 6 wherein an electrically conductive elastomer ring is fitted to at least one of said pillars so as to provide electrical interconnection between said substrates.

8. Micro-element package as claimed in any of claims 1 to 6 wherein at least one of said pillars and the recess in which it is located includes an electrically conductive via which provides electrical interconnection between said substrates.

9. Micro-element package as claimed in claim 8 further including an electrically conductive elastomer pad intermediate said at least one pillar and said recess.

10. Micro-element package as claimed in any of claims 1 to 7 wherein at least one of said pillars and the recess in which it is located includes a fluidic via or bore which provides fluidic interconnection between said substrates.

11. Micro-element package as claimed in claim 10 further including a fluidic seal between said at least one pillar and said recess.

12. Micro-element package as claimed in any of the preceding claims wherein said gasket provides electrical interconnection between said substrates by means of one or more upstanding columns thereon which are vertically electrically conductive.

13. Micro-element package as claimed in claim 12 wherein said columns are vertically electrically conductive by means of oriented conductive wires embedded therein.

14. Micro-element package as claimed in claim 12 wherein said columns are made from a metal-filled compliant elastomer, for example metal-loaded silicone.

15. Micro-element package as claimed in any of the preceding claims wherein one of said substrates is provided with said pillars on one surface thereof and is provided with recesses for receiving pillars of another substrate on the opposing surface thereof.

16. Micro-element package substantially as described herein with reference to any appropriate combination of the accompanying drawings.

17. Gasket for use in a micro-element package wherein said gasket provides electrical interconnection between substrates within the micro-element package by means of one or more upstanding columns thereon which are vertically electrically conductive.

18. Gasket as claimed in claim 17 wherein said columns are vertically electrically conductive by means of oriented conductive wires embedded therein.

19. Gasket as claimed in claim 17 wherein said columns are made from a metal-filled compliant elastomer, for example metal-loaded silicone.

20. Gasket for use in a micro-element package substantially as described herein with reference to any appropriate combination of the accompanying drawings.

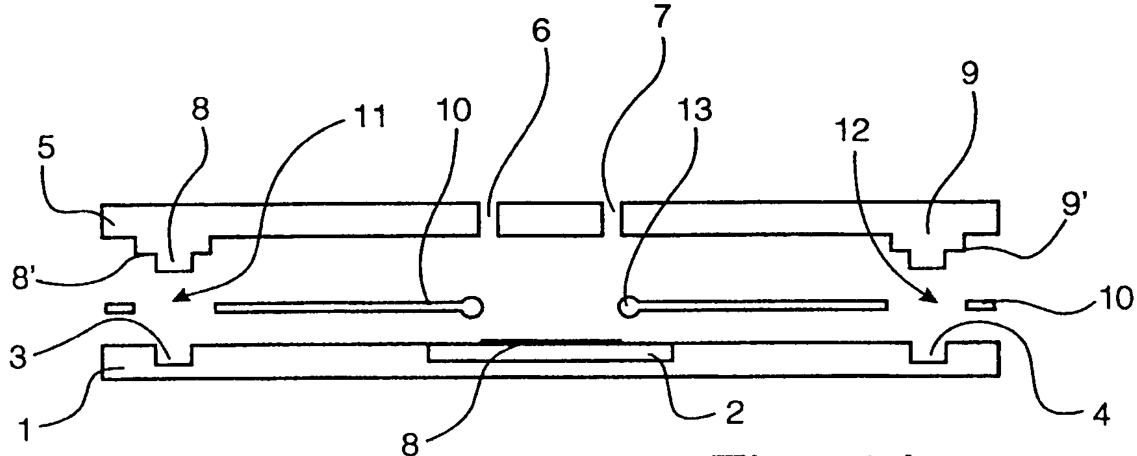


Fig. 1A

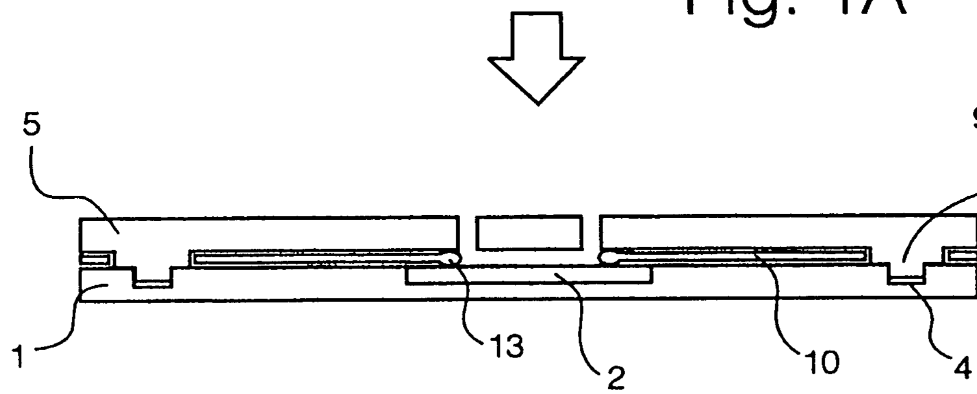


Fig. 1B

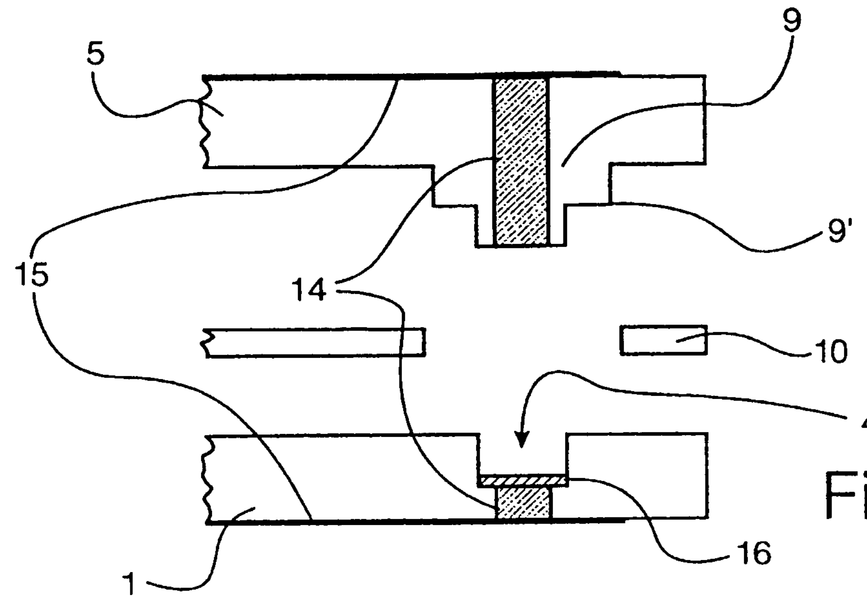


Fig. 2A

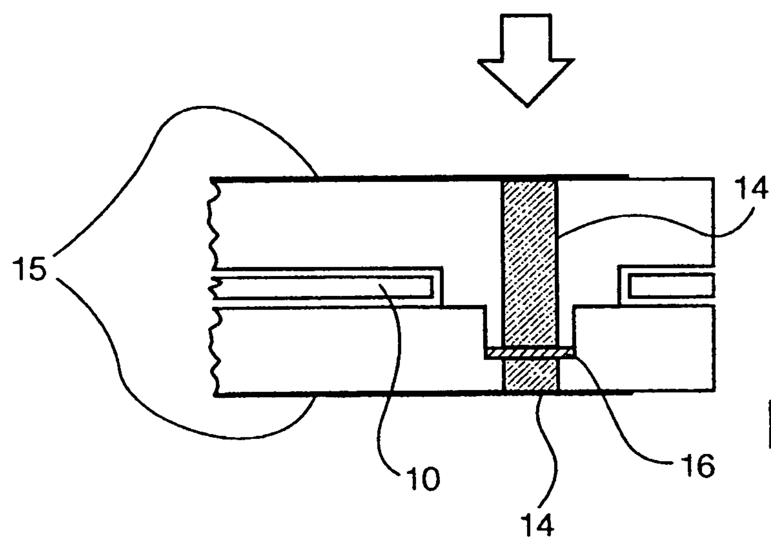


Fig. 2B

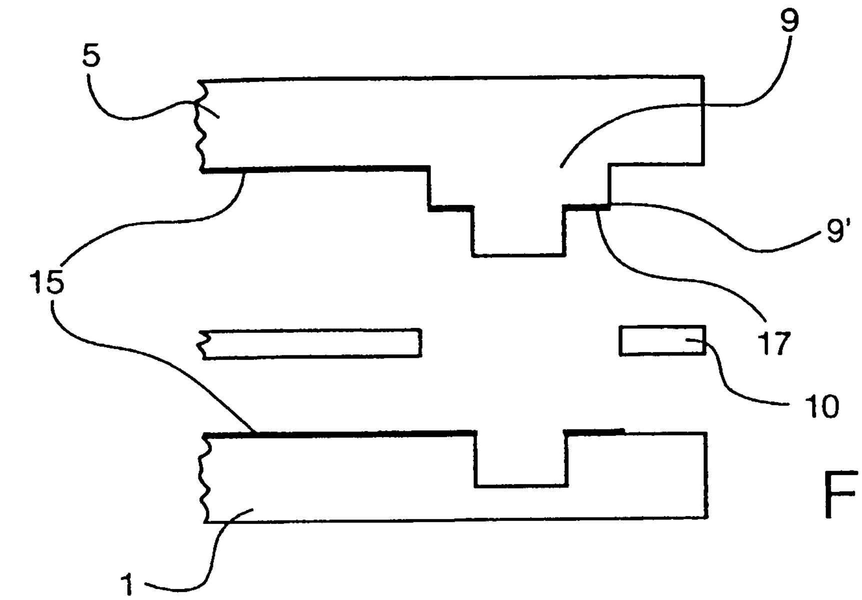


Fig. 3A

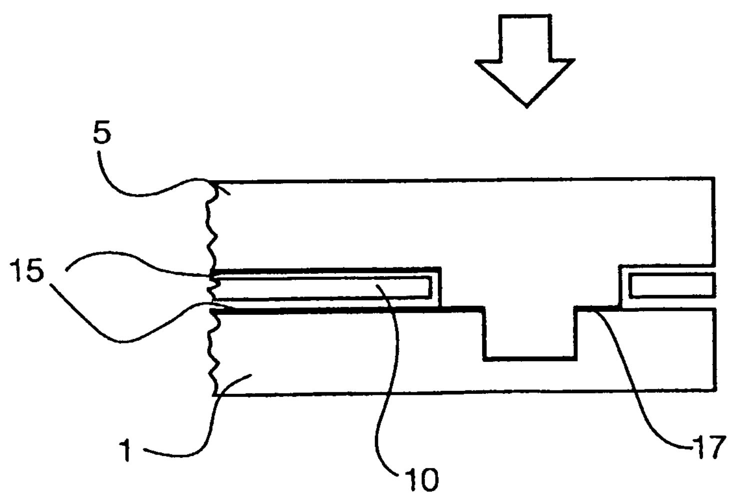


Fig. 3B

Fig. 5A

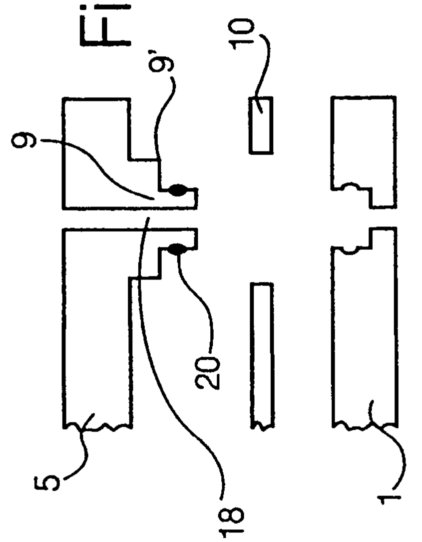


Fig. 5B

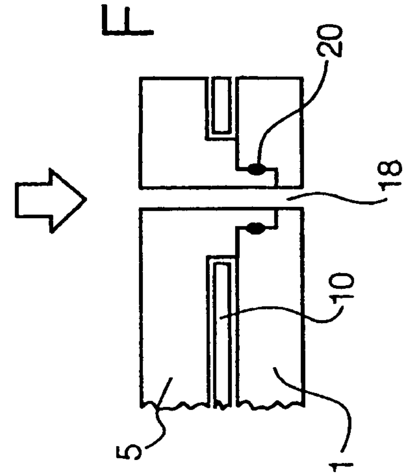


Fig. 4A

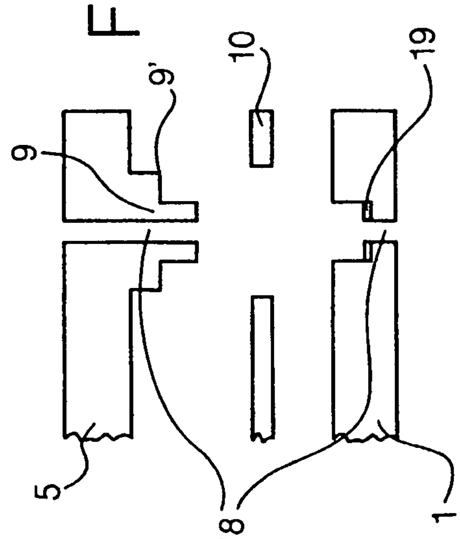
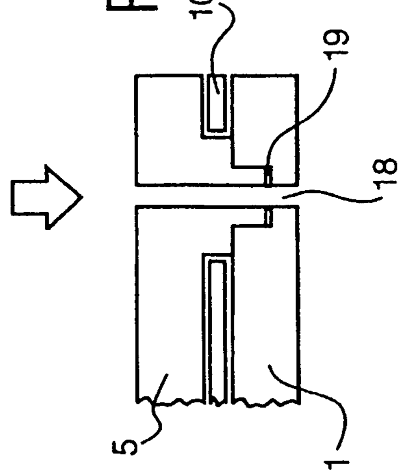


Fig. 4B



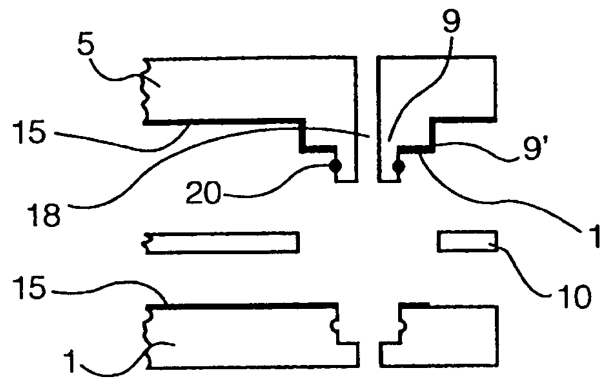


Fig. 6A

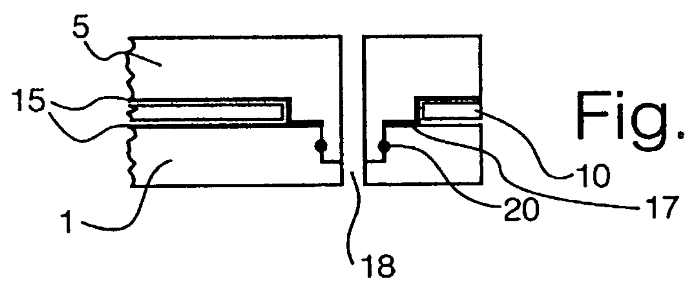


Fig. 6B

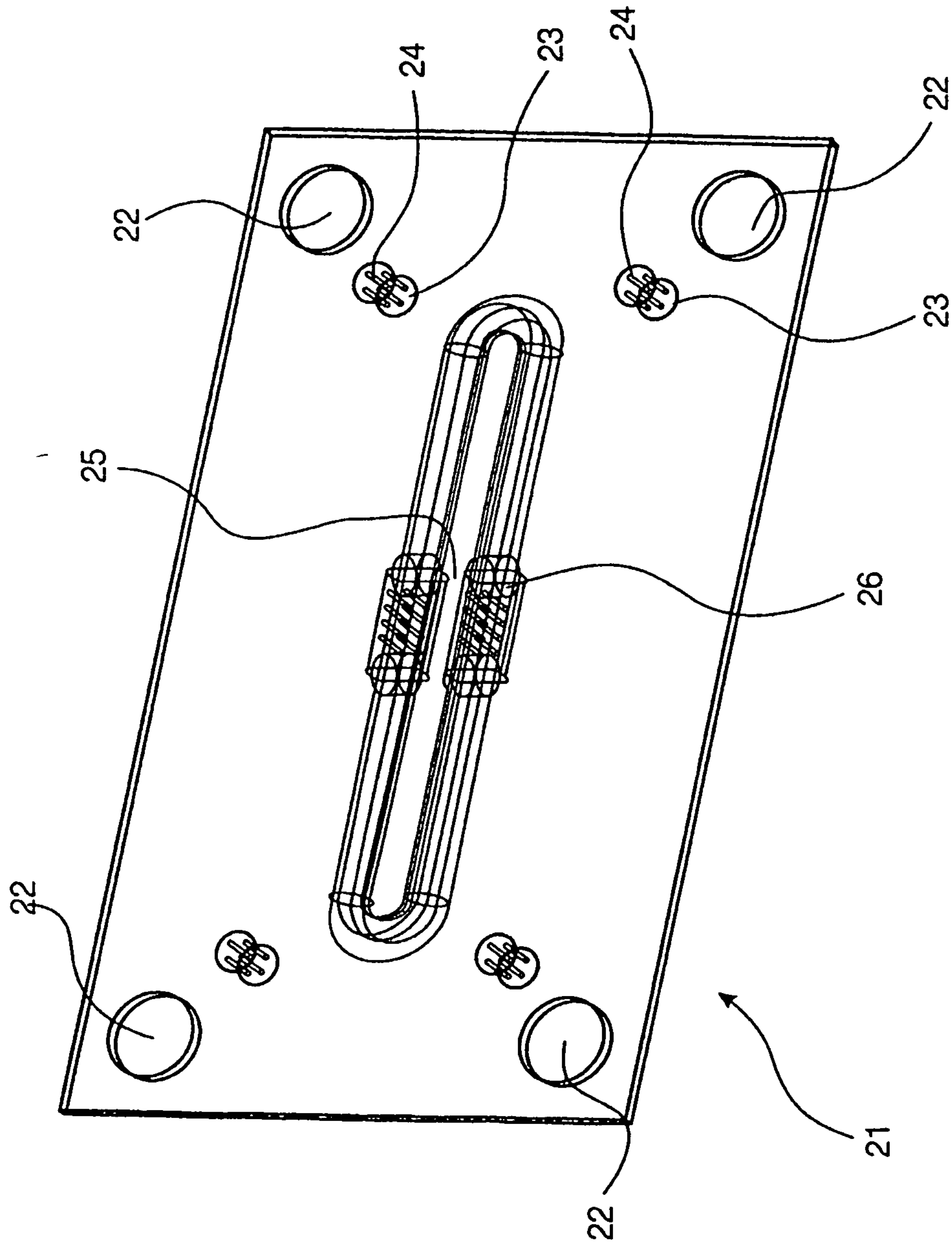


Fig. 7

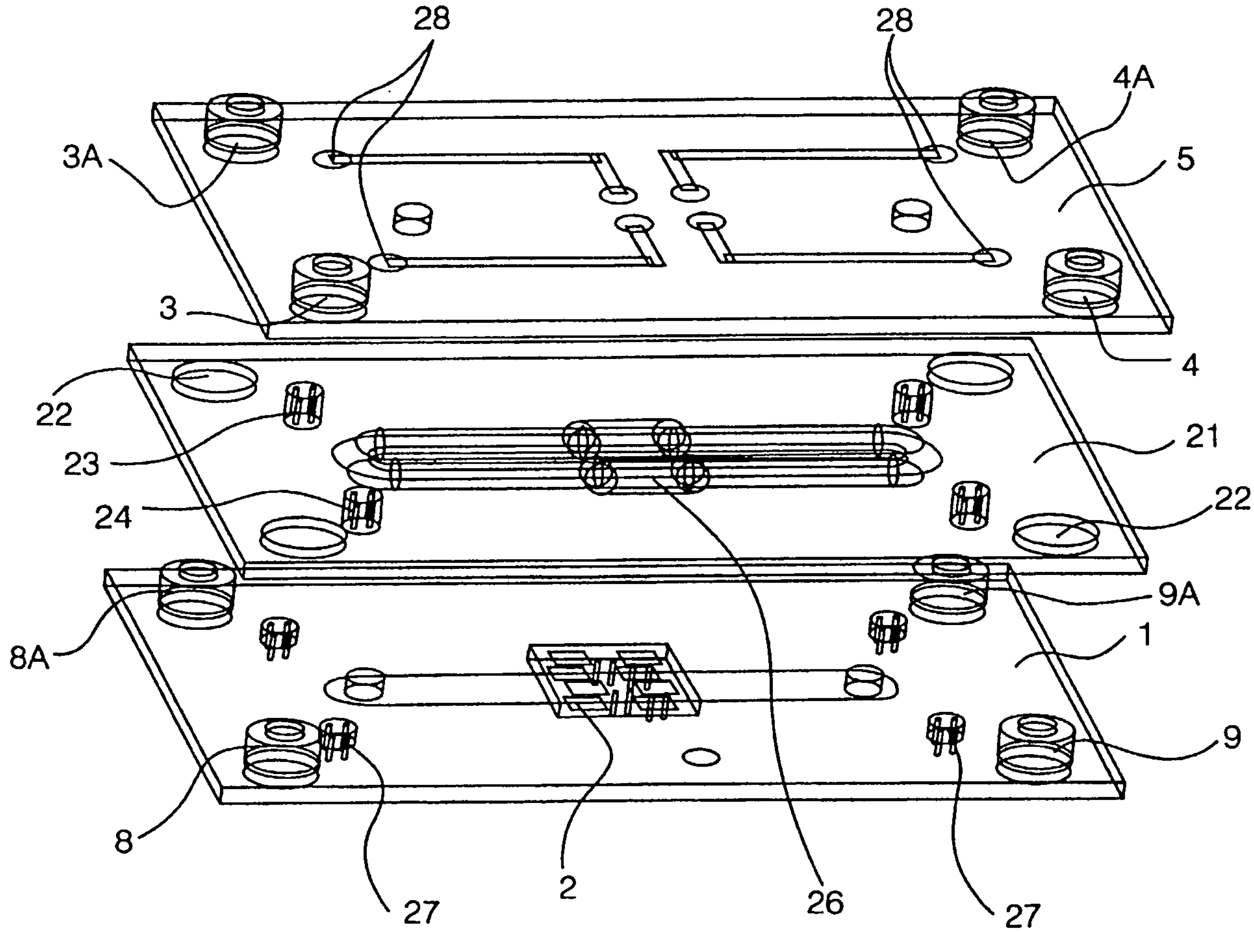


Fig. 8